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(54) IMPROVEMENTS IN OR RELATING TO SPEED CONTROL OF SQUIRREL-CAGE MOTORS

(71) We, GRUNDFOS A/S, a Danish Body Corporate, of 8850 Bjerringbro, Denmark, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of stepwise speed control of a three-phase squirrel-cage motor (asynchronous motor) having three-phase stator coils comprising a set of main windings and a set of additional windings, and to the combination of such a squirrel-cage motor and means for interconnecting the windings to provide stepwise speed control.

In connection with the starting of squirrel-cage motors it is known in the art to switch the stator windings from star connection to delta connection in order to limit the starting current. The switching-over may further be used to control the speed after the starting. Thereby, however, it is only possible to obtain two different speeds of rotation at a particular load unless for example a transformer with a variable tap is inserted (a variotransformer).

According to one aspect of this invention there is provided a method of stepwise speed control of a three-phase squirrel-cage motor having three-prase stator coils comprising a set of main windings and a set of additional windings, each main winding being serially connected to a respective one of the additional windings, the method comprising the steps of first connecting the respective pairs of windings in star to power supply terminals of the motor, then connecting the additional windings in delta and to the power supply terminals via the main windings, then connecting the main windings in star to the power supply terminals whilst the free ends of the additional windings are unconnected, then connecting the respective pairs of windings in delta to the power supply terminals, and finally connecting the main windings in delta to the power supply terminals whilst the free ends of the additional windings are unconnected.

According to another aspect of this invention there is provided in combination, a three-phase squirrel-cage motor having three-phase stator coils comprising a set of main windings and a set of additional windings, each main winding being serially connected to a respective one of the additional windings and, for providing stepwise speed control of the motor, means arranged to interconnect sequentially the windings in accordance with the following sequence of arrangements:

(a) the respective pairs of windings in star to power supply terminals of the motor,

(b) the additional windings in delta and connected to the power supply terminals via the main windings,

(c) the main windings in star to the power supply terminals and the free ends of the additional windings unconnected,

(d) the respective pairs of windings in delta to the power supply terminals, and

(e) the main windings in delta to the power supply terminals and the free ends of the additional windings unconnected.

The invention will be described in greater detail below with reference to the drawings, in which

Figure 1 is a diagram of a first connection of main windings and additional windings in the stator coils in a squirrel-cage motor,

Figure 2 is a diagram of a second connection of the main and the additional windings,

Figure 3 is a diagram of a third connection of the main and the additional windings,

Figure 4 is a diagram of a fourth connection of the main and the additional windings,

Figure 5 is a diagram of a fifth connection of the main and the additional windings,

Figure 6 is a diagram of a connection system employing removable electrically conductive links for obtaining the above five different connections and

Figure 7 shows graphs of the torque of the motor as a function of the speed of rotation, for each of the above-mentioned five different connections.

The stator coils shown in Figures 1—5 belonging to a three-phase squirrel-cage

motor comprises a set of main windings H1, H2, and H3 of equal value, being connectible either in star or in delta, and one set of additional windings T1, T2, and T3 also connectible either in star or in delta. Also in the individual set of additional windings the windings are of equal value. The main windings are connected between terminals 6 and 2, 5 and 1, and 4 and 3, respectively, and the additional windings are connected between terminals 12 and 8, 11 and 7, and 10 and 9, respectively, as shown in Figure 6. The individual additional windings T1, T2 and T3 are permanently connected by respective permanent links (2—12), (1—11) and (3—10) as shown in Figure 6 to the main windings H1, H2 and H3, to provide three pairs of windings (H1, T1), (H2,T2) and (H3,T3). In each of these pairs, winding sense of the main winding is the same as that of its associated additional winding. As will be described more fully later, the main windings are energized in each of five connections of the main and additional windings, whereas the additional windings are energized in only three of the five connections and are unenergized in the other two connections.

As shown in Figure 6, the free ends of main windings H1, H2 and H3 are connected to respective terminals 6, 5 and 4 to which the three phases T, S and R of a three-phase power supply are connected.

In a first connection — see Figure 1 — of the main windings H1, H2, H3 and the additional windings T1, T2, T3 of the stator coils, the additional windings have their free ends, respectively connected to terminals 8, 7 and 9, connected together by a removable conductive link 2 whereby the main windings and additional windings are connected in star. In this connection between the main and the additional windings H1, H2, H3 and T1, T2, T3 the windings use a rather small amount of current. The torque of the rotor being primarily determined by the current is consequently rather small.

In a second connection of main and additional windings H1, H2, H3 and T1, T2, T3 — see Figure 2 — the additional windings T1, T2, T3 are connected in delta, with the main windings H1, H2, H3 being disposed between the respective terminals of the delta and the respective phase connecting terminals 4, 5, and 6, by means of respective removable links 3 linking terminals 7 and 10, 8 and 11, and 9 and 12. In this connection of the main and additional windings H1, H2, H3 and T1, T2, T3 the windings use a little larger amount of current, the delta connection of the additional windings being, as is well known, less reactive than the above-mentioned star connection of the same additional windings. Also the torque of the rotor will for a given speed of rotation be a little larger even though the magnetic field produced by a main winding H1, H2, H3 will then not be entirely in phase with the field produced by a corresponding additional winding T1, T2, or T3 respectively.

In a third connection — see Figure 3 — terminals 1, 2 and 3 are connected together by a removable conductive link 2, and terminals 7, 8 and 9 are left unconnected. Hence the additional windings are unenergized and the main windings are connected in star, and thus the current with which the main windings H1, H2, H3 load the three phases R, S, and T is increased. With this connection the torque is greater than with the connections of Figures 1 and 2 at the given speed of rotation.

In a fourth connection of the main windings H1, H2, and H3 and the additional windings T1, T2 and T3 — see Figure 4 — the pairs of windings (H1,T1), (H2,T2) and (H3,T3) are connected in delta by means of respective removable conductive links 3 linking terminals 4 and 7, 5 and 8, and 6 and 9. This connection of the main windings H1, H2, and H3 and the additional windings T1, T2, and T3 will, if the impedance of an additional winding is less than twice that of a main winding, carry more current than the stator coils shown in Figure 3 at the given speed of rotation, and hence the torque will be increased.

In a fifth connection of the stator coils the main windings H1, H2, H3 are connected in delta to the three phases R, S and T, and the additional windings are unenergized, the terminals 7, 8 and 9 not being connected to the power supply; thereby the load current and the torque are increased. This connection is obtained by moving the links 3 such that they link terminals 1 and 4, 2 and 5, and 3 and 6, respectively.

By means of the above connections of the main and the additional windings of the stator coils a method has thus been provided of changing over between five different torques, measured at the given speed of rotation of the squirrel-cage motor. This change-over may preferably be effected by arranging the terminals in four rows as shown in Figure 6 which facilitates their linking by the link 2 and links 3.

Thus, it is possible to control the torque of a squirrel-cage motor without using a voltage adjusting transformer with a variable tap or the like.

The method according to the invention may for example be used for stepwise controlling the speed of squirrel-cage motors driving pumps or ventilators, in which it is often necessary to have more than two speeds of rotation. It is known that a stable speed of rotation for a given connection of the stator coils will be obtained if the torque

of the motor increases when the speed of rotation decreases, corresponding with an increasing slip. This may be obtained in a known manner by providing the rotor or its winding with a significant resistance. If the squirrel-cage motor is a slip-ring motor, said resistance may be the starting resistance. Figure 7 shows the torque of a motor as a function of the speed of rotation corresponding to a frequency of 50 Hz. At a torque of 0 kp . m the speed of rotation is

$$50 \frac{\text{rotations}}{\text{seconds}} \cdot 60 \frac{\text{seconds}}{\text{minute}} = 3000 \frac{\text{rotations}}{\text{minute}}$$

corresponding to the slip being 0%. When the torque increases the speed of rotation of the motor decreases approximately along a straight line (i.e. the curves marked connection 1 to connection 5) as is usual in squirrel-cage motors or asynchronous motors with electric resistance in the current paths of the rotor, as mentioned above. In the figure further a mechanical load is marked, the value of said mechanical load increasing with the square of the speed of rotation. A pump or a ventilator has approximately such a load characteristic. With such a load the motor will after each change-over from one to another of the above-mentioned connections of main and additional windings come to a steady running speed given by the intersection between the mechanical load line and the torque/speed characteristic for said other connection to which the stator coils were changed.

WHAT WE CLAIM IS:—

1. A method of stepwise speed control of a three-phase squirrel-cage motor having three-prase stator coils comprising a set of main windings and a set of additional windings, each main winding being serially connected to a respective one of the additional windings, the method comprising the steps of first connecting the respective pairs of windings in star to power supply terminals of the motor, then connecting the additional windings in delta and to the power supply terminals via the main windings, then connecting the main windings in star to the power supply terminals whilst the free ends of the additional windings are unconnected, then connecting the respective pairs of windings in delta to the power supply terminals, and finally connecting the main windings in delta to the power supply terminals whilst the free ends of the additional windings are unconnected.

2. A method of stepwise speed control of a squirrel-cage motor substantially as hereinbefore described with reference to the drawings.

3. In combination, a three-phase squirrel-cage motor having three-phase stator coils comprising a set of main windings and a set of additional windings, each main winding being serially connected to a respective one of the additional windings and, for providing stepwise speed control of the motor, means arranged to interconnect sequentially the windings in accordance with the following sequence of arrangements:

(a) the respective pairs of windings in star to power supply terminals of the motor,

(b) the additional windings in delta and connected to the power supply terminals via the main windings,

(c) the main windings in star to the power supply terminals and the free ends of the additional windings unconnected,

(d) the respective pairs of windings in delta to the power supply terminals, and

(e) the main windings in delta to the power supply terminals and the free ends of the additional windings unconnected.

4. A combination of three-phase squirrel-cage motor and interconnection means, substantially as hereinbefore described with reference to the drawings.

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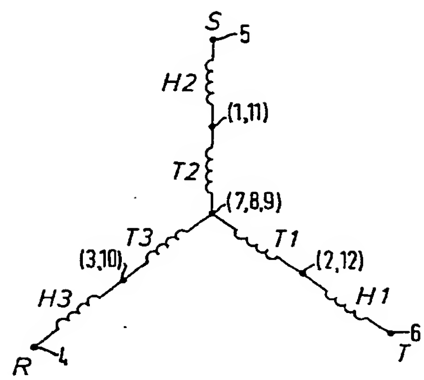

S
5
H2
(1,11)
T2
(7,8,9)
T3
T1
(3,10)
(2,12)
H3
H1
R
4
T
6

Fig. 1

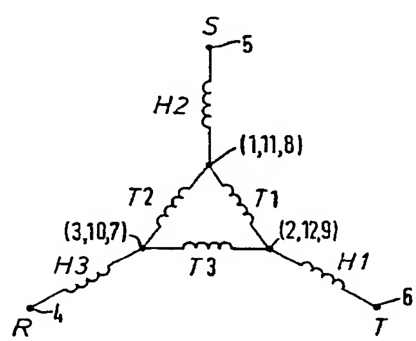

S
5
H2
(1,11,8)
T2
T1
(3,10,7)
(2,12,9)
H3
T3
H1
R
4
T
6

Fig. 2

Fig. 3

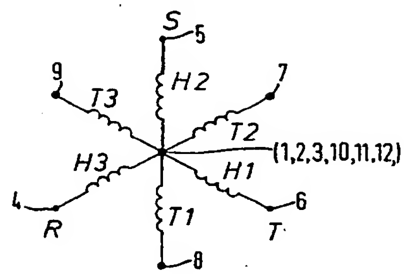


Fig. 4

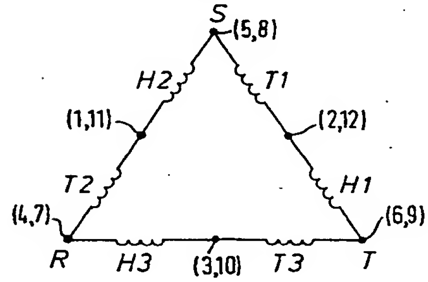
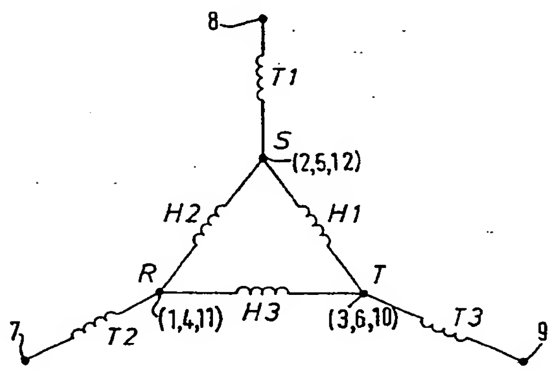


Fig. 5



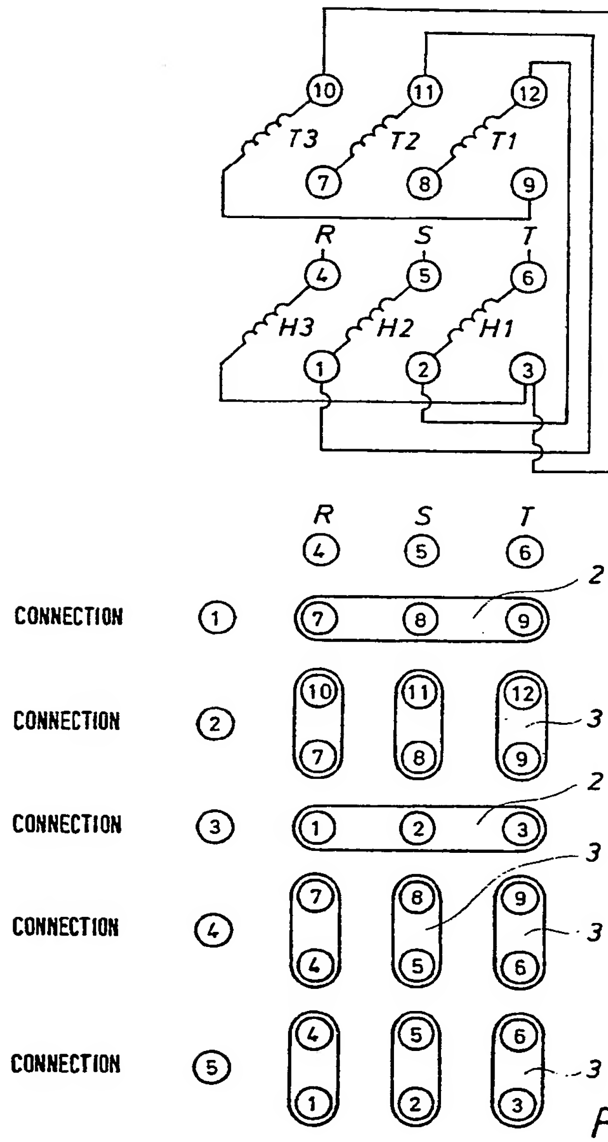

10
11
12
T3
T2
T1
7
8
9
R
S
T
4
5
6
H3
H2
H1
1
2
3
CONNECTION 1
CONNECTION 2
CONNECTION 3
CONNECTION 4
CONNECTION 5
2
3

Fig. 6

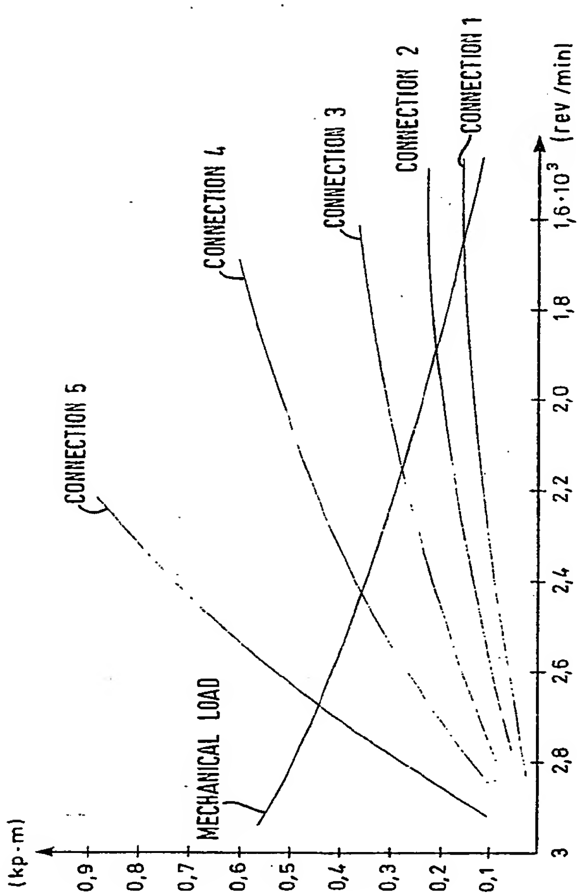

CONNECTION 1
CONNECTION 2
CONNECTION 3
CONNECTION 4
CONNECTION 5
MECHANICAL LOAD
(kp·m)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
3
2,8
2,6
2,4
2,2
2,0
1,8
1,6·10³
(rev/min)

Fig. 7